C-A Unreviewed Safety Issue (USI) Form

Title of USI: ODH Evaluation of STAR and PHENIX ODH Barrier Relocations

Description of USI (use attachments if necessary):
The attached analysis by A. Pendzick documents the safety of moving the ODH barriers from the end of a DX magnet to approximately the middle of the DX magnet. Based on this analysis, the ODH classification of the STAR and PHENIX Intersection Regions remain unclassified. The C-A ASSRC Chair has agreed with the conclusions of this anaysis.

Title and Date of Relevant SAD: RHIC SAD, 12/31/1999

Committee Chair or ESHQ Division Head must initial all items. Leave no blanks:

ITEM	APPLIES	DOES NOT APPLY
Decision to not revise the current SAD and/or ASE at this time: The hazard associated with the proposed work or event is covered within an existing SAD and/or ASE. SAD Title and Date: RHIC SAD, 12/31/1999 This Form and attachments, if necessary, shall be used to document the USI until the next revision of the appropriate SAD.	Rel Rel	
Decision to submit a revised SAD and/or ASE to the BNL ESH Committee: The hazard associated with the proposed work is not appropriately included in an SAD.		Rel Rel

Ray Karol
Signature of C-A Committee Chair or C-A ESHQ Division Head

5/7/02
Date

Edward T Lessard
Signature of C-A Associate Chair for ESHQ

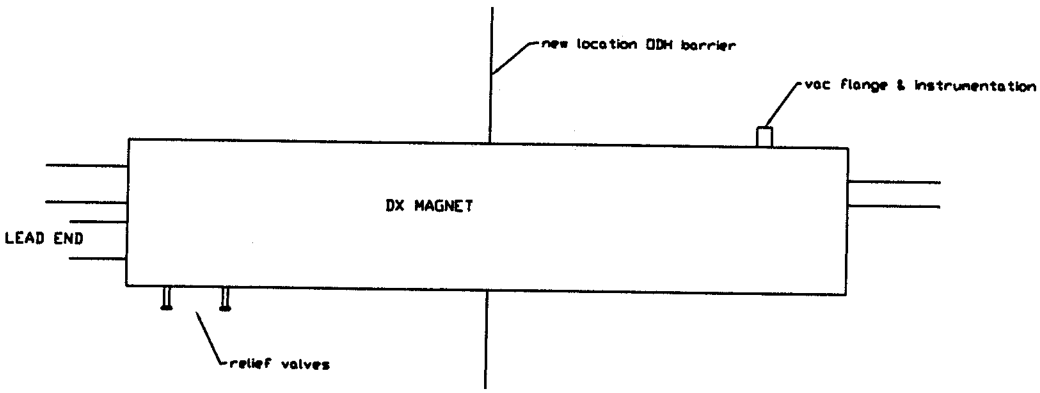
5-7-02
Date

ODH risk assessment for STAR & PHENIX ODH barrier relocations

Star & Phenix have proposed to relocate the ODH barriers from the end of a DX magnet to approximately the middle of their DX magnet, preferably without changing the ODH classification of their Intersection regions. In each case this will place one-half the DX vacuum tank, vacuum piping & instrumentation in the presently non-classified IR areas. While a solution that does not include moving the barrier for STAR may be possible, it is not likely a similar solution can be found for PHENIX.

In the following, I attempt to assess the ODH risk on the IR side due to this move.

In both cases the new configuration is:



Machine side IR side

In AD/RHIC/RD-71, K.C. Wu assesses the relief valve requirements for RHIC magnets and concludes that one relief valve for every 2 RHIC magnets is adequate. DX magnets have 2ea-2" relief valves set at 3 to 4 psi differential pressure. A conservative estimate of the pressure rating of the vacuum vessel and components is 15 psi.

Assuming a sequence of events that leads to the failure of the vacuum tank or components on the IR side & the probability of this event: (from SBMS subject area)

1) leak or rupture of the magnet ---------------------------2x10-7

2) relief 1 fails to open ----------------------------1x10-5
3) relief 2 fails to open ----------------------------1x10-5
4) failure to relieve to the triplet --------------------------- no data
5) failure of the vacuum vessel or vacuum instrumentation, releasing cryogens into the IR ---------------------------- 1

The ODH fatality rate for this sequence, assuming:

The relief valve failures are independent events
The fatality factor is 1 if cryogens are released in the IR

O = P F
O = (P1)(P2)(P3) (F)
O = (2x10-7) (1x10-5) (1x10-5)(1)
O = 2x 10-17 fatalities/hr

The criteria for a non-classified ODH area is 1x10-9 fatalities/hr, therefore using these assumptions, the STAR & PHENIX Intersection Regions can remain non-ODH areas.

EQUIPMENT FAILURE AND HUMAN ERROR RATES

Additional Risk Assessment Data

Table B-I gives estimates of cryogenic equipment failure rates. These data are median estimates collected from past ODH risk assessments performed on systems at Fermilab. This data has been updated to include the revised failure rate estimates as described by B. Soyars (Fermilab) report, "Appendix: Rationale for Table 1 – Fermilab Equipment Failure Rate Estimates," dated January 26, 2000. Table B-II shows failure rates for various equipment types derived from the nuclear power industry that may be useful as input data (MOV – Manually operated valves/SOV - Solenoid operated valves/AOV – Automatically operated valves). General human error rate estimates are presented in Table B-III. Table B-IV lists conservative estimates of the rate of human error as a function of task type and time limit.

TABLE B-I FERMILAB EQUIPMENT FAILURE RATE ESTIMATES		
Component	Failure Mode	Estimated Median Failure Rate
Compressor (Cryogenic)	Leak Rupture	$5 X 10^{-6}$/HR $3 X 10^{-7}$/HR
Dewar	Leak or Rupture	$1 X 10^{-6}$/HR
Electrical Power Failure (unplanned)	Time Rate Demand Rate Time Off	$1 X 10^{-4}$/HR $3 X 10^{-4}$/Demand 1 HR
Fluid Line (Cryogenic)	Leak Rupture	$5 X 10^{-7}$/HR $2 X 10^{-8}$/HR
Magnet (Cryogenic, Powered, unmanned)	Leak or Rupture	$2 X 10^{-7}$/HR
Magnet (Cryogenic, Not Powered, unmanned)	Leak or Rupture	$2 X 10^{-8}$/HR
Header Piping Assembly	Rupture	$1 X 10^{-8}$/HR
Change of Equipment with Bayonet Fitting (Cryogenic Release)	Small Event Large Event	$3 X 10^{-2}$/Demand $1 X 10^{-3}$/Demand

TABLE B-II U.S. NRC EQUIPMENT FAILURE RATE ESTIMATES		
COMPONENT	FAILURE MODE	FAILURE RATE
Battery Power Supplies	No Output	$3x10^{-6}$/hr
Circuit Breakers	Failure to Operate	$1x10^{-3}$/demand
	Premature Transfer	$1x10^{-6}$/hr
Diesel (Complete Plant)	Failure to Start	$3x10^{-2}$/demand
	Fails to Run (Emergency loads)	$3x10^{-3}$/hr
	Fails to Run (Engine Only)	$3x10^{-4}$/hr
Electric Motors	Failure to Start	$3x10^{-4}$/demand
	Fails to Run	$1x10^{-5}$/hr
	Fails to Run (Extreme Environment)	$1x10^{-3}$/hr
Fuses	Premature Open	$1x10^{-6}$/hr
	Failure to Open	$1x10^{-5}$/demand
Gaskets	Leak	$3x10^{-6}$/hr
Flanges/Closures/Elbows	Leak/Rupture	$3x10^{-7}$/hr
Instrumentation (Amplification, Annunciators, Transducers, Calibration, Combination)	Failure to Operate	$1x10^{-6}$/hr
	Shifts	$3x10^{-5}$/hr
Pipes >3" (High Quality)	Rupture (section)	$1x10^{-10}$/hr
Pipes <3" (High Quality)	Rupture	$1x10^{-9}$/hr
Pumps	Failure to Start	$1x10^{-3}$/demand
	Fails to Run	$3x10^{-5}$/hr
	Fails to Run (Extreme Environment)	$1x10^{-3}$/hr
Relays	Failure to Energize	$1x10^{-4}$/demand
	Failure NO Contact to Close	$3x10^{-7}$/hr
	Short Across NO/NO Contacts	$1x10^{-8}$/hr
	Open NC Contact	$1x10^{-7}$/hr
Solid State Devices (High Power Applications)	Failure to Function	$3x10^{-6}$/hr
	Shorts	$1x10^{-6}$/hr
Solid State Devices (Low Power Applications)	Failure to Function	$1x10^{-6}$/hr
	Shorts	$1x10^{-7}$/hr
Transformers	Open	$1x10^{-6}$/hr
	Short	$1x10^{-6}$/hr
Switches	Limit - Fails to Operate	$3x10^{-4}$/demand
	Torque - Fails to Operate	$1x10^{-4}$/demand
	Pressure - Fails to Operate	$1x10^{-4}$/demand
	Manual - Fails to Transition	$1x10^{-5}$/demand
	Manual – Contact Shorts	$1x10^{-8}$/hr
Valves: MOV	Fails to Operate	$1x10^{-3}$/demand
	Fails to Remain Open (plug)	$1x10^{-4}$/demand
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: SOV	Fails to Operate	$1x10^{-3}$/demand
Valves: AOV	Fails to Operate	$3x10^{-4}$/demand
	Fails to Remain Open (plug)	$1x10^{-4}$/demand
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: Check	Fails to Operate	$1x10^{-4}$/demand
	Reverse Leak	$3x10^{-7}$/hr
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: Vacuum	Fails to Operate	$3x10^{-5}$/demand
	Rupture	$1x10^{-8}$/hr
Valves: Orifices, Flow Meters	Rupture	$1x10^{-8}$/hr

TABLE B-II U.S. NRC EQUIPMENT FAILURE RATE ESTIMATES		
COMPONENT	FAILURE MODE	FAILURE RATE
Valves: Manual	Fails to Remain Open (plug)	$1x10^{-4}$/demand
Valves: Relief	Fails to Open	$1x10^{-5}$/demand
	Premature Open	$1x10^{-5}$/hr
Welds	Leaks	$3x10^{-9}$/hr
Wires	Open	$3x10^{-6}$/hr
	Short to Ground	$1x10^{-7}$/hr
	Short to Power	$1x10^{-8}$/hr

TABLE B-III HUMAN ERROR RATE ESTIMATES	
Estimated Error Rate ($Demand^{-1}$)	Activity
10^{-3}	Selection of a switch (or pair of switches) dissimilar in shape or location to the desired switch (or pair of switches), assuming no decision error. For example, operator actuates large handled switch rather than small switch.
3×10^{-3}	General human error of commission, e.g., misreading label and therefore selecting wrong switch.
10^{-2}	General human error of omission where there is no display in the control room of the status of the item omitted, e.g., failure to return manually operated test valve to proper configuration after maintenance.
3×10^{-3}	Errors of omission, where the items being omitted are embedded in a procedure rather than at the end as above.
$1/x$	Given that an operator is reaching for an incorrect switch (or pair of switches), he selects a particular similar appearing switch (or pair of switches), where x = the number of incorrect switches (or pair of switches) adjacent to the desired switch (or pair of switches). The 1/x applies up to 5 or 6 items. After that point, the error rate would be lower because the operator would take more time to search. With up to 5 or 6 items he doesn't expect to be wrong and therefore is more likely to do less deliberate searching.
10^{-1}	Monitor or inspector fails to recognize initial error by operator. Note: With continuing feedback of the error on the annunciator panel, the high error rate would not apply.
10^{-1}	Personnel on different work shift fail to check condition of hardware unless required by check or written directive.
5×10^{-1}	Monitor fails to detect undesired position of valves, etc., during general walk-around inspection, assuming no check list is used.
.2 - .3	General error rate given very high stress levels where dangerous activities are occurring rapidly.
$2^{(n-1)}x$	Given severe time stress, as in trying to compensate for an error made in an emergency situation, the initial error rate, x, for an activity doubles for each attempt, n, after a previous incorrect attempt, until the limiting condition of an error rate of 1.0 is reached or until time runs out. This limiting condition corresponds to an individual's becoming completely disorganized or ineffective.

AD/RHIC/RD-71

RHIC PROJECT

Brookhaven National Laboratory

Safety Relief for RHIC Vacuum Tank

K. C. Wu

August 1994

SAFETY RELIEF FOR RHIC VACUUM TANK

K. C. Wu

1). INTRODUCTION

The relief systems are required to prevent overpressure in both the pressure vessel containing cold helium and the vacuum tank for the RHIC cryostats. The pressure relief system for the helium vessel has been designed for a catastrophic loss of the insulating vacuum.[1] In this report, the relief system for the vacuum tank is considered. Unlike the helium vessel, the vacuum tank is designed for low pressure. The tank relief is typically set at 3 to 4 psi (0.2 to 0.3 atm) differential and will be of a disc type supported by three or four springs. The venting capacity for a 2 inch relief valve along with the associated longitudinal pressure drops have been calculated. Results suggest that a safe relief system for RHIC could be achieved provided there is one relief valve on every other magnet cryostat.

2). PHENOMENON

The maximum credible accident (MCA) for the vacuum tank assumes a serious failure occurs in the helium system and cold helium is released into the vacuum tank. Because the tank volume is approximately fifty times that of the helium vessel, the initial pressure in the vacuum tank will be considerably lower than the ambient pressure as cold helium expands in the tank. The pressure and temperature then increase through a constant density heating process. When the pressure reaches the relief setting, helium will be vented outside and the process becomes a constant pressure heating process as illustrated in Fig. 1.

FAILURE OCCURS IN HELIUM SYSTEM

-----> COLD HELIUM EXPANDS INTO VACUUM TANK

-----> HEATING AT CONSTANT DENSITY

-----> REACHES 1 ATM AT ABOUT 15 K

-----> PRESSURE INCREASES FURTHER

-----> VENTING WITH HEATING AT CONSTANT PRESSURE

Figure 1. Heating and venting process with relief valve of the vacuum tank

3). HEAT LOAD

The heat load associated with the type of accident under consideration is rather complicated because of the transient processes of conduction and convection in the vacuum space. In an earlier study using warm helium to spoil the vacuum of a RHIC dipole cryostat[2], a 13 kW heat load from the vacuum tank into the cryostat was identified. In principle, the heat transferred from the tank to cold helium in the vacuum space is more. In this study, calculations have been performed to obtain the amount of heat that can be removed by the venting process as a function of the venting pressure for a 2 inch diameter relief valve. For the conditions here, 25 kW is estimated as the heat load for a magnet cryostat. Should the real heat load exceed 25 kW, it will be shown that the pressure inside the vacuum tank will still be lower than one atmosphere differential for heat loads up to three times estimated.

4). VENTING OF HELIUM

When the upstream pressure is less than two times the downstream pressure the flow is at subsonic conditions. The amount of helium $\dot{m}$ (lb/hr) that can be vented through an orifice of area A (in^2) connected to a large volume is given by equation 1. In equation 1, the constant 600 is obtained with an assumed flow resistance coefficient of 1.5 through the orifice.

$$\frac{\dot{m}_{vent}}{A} = 600 \times Y \times \frac{\sqrt{\Delta P \times P}\,\sqrt{M}}{\sqrt{T}} \tag{1}$$

$$Y = \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}} \sqrt{\frac{k}{k-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] / \left(1 - \frac{P_2}{P_1}\right)} \tag{2}$$

where Y is the expansion factor given by equation 2.
P is the upstream pressure, lb/in^2.
ΔP is the differential pressure, lb/in^2.
M is the molecular weight of the gas, 4 for helium.
T is the inlet temperature, in degree R.
k is the specific heat ratio, 5/3 for helium.

subscript *vent* refers to the helium vented through the relief valve.
1 and 2 refer to upstream and downstream of the orifice.

For upstream pressures greater than two times the downstream pressure, the sonic formula given by equation 3 should be used instead

$$\frac{\dot{m}_{vent}}{A} = \frac{C\ K\ P\ \sqrt{M}}{\sqrt{T}} \tag{3}$$

where C is the gas constant, 377 for helium.
K is the valve coefficient of discharge = 0.816.

5). CONSTANT DENSITY HEATING PROCESS

In RHIC, the magnets contain more cold helium than any other helium lines. The failure of a magnet helium containment is considered as the worst accident in sizing the vacuum tank relief. A dipole magnet vacuum tank is about 3000 liters in volume and there are 67 liters of supercritical helium in the dipole magnet. When 67 liters of supercritical helium are released into the 3000 liter vacuum tank, the initial pressure and temperature in the vacuum tank become 0.27 atms and 4.5 K. The constant density heating process will heat the helium to higher temperatures and pressures as shown in Table 1. From Table 1, the temperature at which the relief valve opens can be determined from the set pressure of the valve.

Table 1. Pressure and temperature for the constant density heating process

Pressure - atm	Temperature - K
1.2	19.1
1.4	22.2
1.6	25.4
1.8	28.5
2.0	31.7
2.5	39.5

6). CONSTANT PRESSURE HEATING PROCESS

Although the Table 1 tank pressure (1.2 to 2 atms) at which the relief valve opens is less than the critical pressure of helium, the temperature is greater than the critical temperature. Therefore no phase change occurs when the relief opens. The heating process from thermodynamic state 1 to state x at a higher temperature with helium venting through a relief valve can be illustrated by Fig. 2.[3]

State 1		State x		Helium Relieved Through Safety Device
m_1		m_x		$(m_1 - m_x)$
P_1	$\rightarrow$	P_x	$+$	$P_x = P_1$
T_1		T_x		$T_1 \rightarrow T_x$
h_1		h_x		$h_1 \rightarrow h_x$
ρ_1		ρ_x		$\rho_1 \rightarrow \rho_x$

Fig. 2 Heating process from state 1 to x with helium venting through relief valve.

where P is the pressure
T is the temperature
m is the mass of helium
h is the enthalpy
ρ is the density
and subscripts 1 and x refer to thermodynamic states 1 and x.

The heat absorbed by the helium vapor for any such incremental step can be approximated by equation 4. The heat absorbed per unit mass of helium leaving the container is given in equation 5.

$$q = m_x (h_x - h_1) + (m_1 - m_x) \frac{(h_x - h_1)}{2} \tag{4}$$

$$L' = \frac{q}{(m_1 - m_x)} = \frac{(h_x - h_1)(m_1 + m_x)}{2 (m_1 - m_x)} \tag{5}$$

where m , h , 1 and x are as defined above
and q is amount of heat absorbed
L' is the heat absorbed per unit mass of helium leaving the container

The heating rate $\dot{Q}$ during the constant pressure venting process equals the amount of helium to be vented multiplied by the heat absorbing capability as shown in equation 6. In equation 4 through 6, the specific heats from the magnet and other components of the magnet are neglected.

$$\dot{Q} = \dot{m}_{vent} \times L' \tag{6}$$

7). HEAT REMOVING CAPACITY

Based on the initial conditions and the parameters of the cryogenic system, the relief requirements have been calculated for relief pressures from 1.2 to 2.5 atms absolute, i.e. 0.2 to 1.5 atm differential. The detailed results including the constant density and constant pressure heating processes are given in the appendix. A summary of the heat removing capacity for a 2 inch diameter relief as a function of relief pressure is given in Table 2. As one can see, the heat removing capacity increases from about 50 kW to over 200 kW when the relief pressure is increased from 1.2 to 2.5 atms. The pressure difference between the inside of the vacuum tank and the ambient is 0.2 to 1.5 atm. As a general rule, the pressure rating for a vacuum vessel should be at least 1 atm differential. Simple calculation shows that the 1/4" wall 24" O.D. RHIC cryostat can sustain an internal pressure of 5 atm. However, the exact pressure rating for other components of the cryostat can not be obtained as easily.

Table 2. Heat removing capability as a function of relief pressure for the vacuum tank

Pressure atm absolute	Total Area of Relief in^2	Temp. Relief Opens K	Max. Mass Flow g/s	Heat. Removing Capacity kW
1.2	3.14	19.1	523	53
1.4	3.14	22.2	687	81
1.6	3.14	25.4	803	108
1.8	3.14	28.5	863	130
2.0	3.14	31.7	936	157
2.5	3.14	39.5	1035	216

8). SYSTEM INTEGRATION

As can be seen from Table 2, the heat removing capacity for a 2 inch diameter relief valve set at 1.2 atms is 53 kW. This is about twice the 25 kW estimated heat load. Therefore a 2 inch relief is suitable for two magnets. The heat load would have to be three times greater than the estimate before the differential pressure seen by the vacuum tank reaches one atmosphere.

While the cross section of the cryostat is 24 inch in diameter, there are superinsulations, heat shield and cold helium lines inside. Identification of equivalent diameter for pressure drop calculation is required. In Table 3, the longitudinal helium conductances and the equivalent round conduit are given by Kimo Welch[4] from measurements in Full Cell #2.

Table 3. Conductance and equivalent diameter for RHIC cryostats

Cryostat	Conductance	Equivalent Diameter
Dipole Cryostat:	89 L/s	14.0 cm
Standard CQS Cryostat:	152 L/s	13.3 cm
CQS Cryostat w/ Recooler:	307 L/s	16.8 cm

The pressure drop that may occur longitudinally is calculated for a 10 meter dipole cryostat with different venting condition. The results are given in Table 4. As one can be, the longitudinal pressure is not a concern if there is one relief for one or two magnets. Since there are multiple relief valves installed in RHIC, there is no need to install redundant relief valve.

Table 4. Pressure drop for a RHIC dipole cryostat at venting condition shown in Table 2

Pressure atm	Temperature K	Flow Rate g/s	Pressure Drop atm
1.2	19.1	523	0.002
1.4	22.2	687	0.003
1.6	25.4	803	0.003
1.8	28.5	863	0.004
2.0	31.7	936	0.005
2.5	39.5	1035	0.006

REFERENCES

1. K. C. Wu, "Pressure relief for RHIC cryogenic system", RHIC Project Tech. Note AD/RHIC/RD-64, Dec. 1993.
2. R. H. Kropschot, B. W. Birmingham and D. B. Mann, "Technology of Liquid Helium", National Bureau of Standards, Monograph 111, Oct. 1968.
3. K. C. Wu, D. P. Brown, J. Sondericker and D. Zantopp, "An experimental study of catastrophic loss of vacuum for RHIC dipole in MAGCOOL", in "Advances in Cryogenic Engineering", Vol. 39A, p987, Plenum Press, New York (1993).
4. Kimo Welch, "Cryostat Longitudinal Helium Conductances", Memo to K. C. Wu, Dec. 16, 1993.

APPENDIX:

Requirements and operating conditions for

the relief valves of the RHIC vacuum tank

Please enter remarks
Chenk the heat absorbing capability for a 2 inch vent in RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.2
qheat-kW
53

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.36	5.96	.003	9.2	32.60	.79
.45	7.42	.003	9.2	37.13	.79
.55	8.89	.003	9.2	41.72	.80
.64	10.35	.003	9.2	46.25	.79
.73	11.81	.003	9.2	50.81	.79
.83	13.27	.003	9.2	55.33	.79
.92	14.74	.003	9.2	59.93	.80
1.01	16.20	.003	9.2	64.46	.79
1.11	17.65	.003	9.2	68.99	.79
1.20	19.10	.003	9.2	73.52	.79

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
19.1	.003	113.1	20.1	.003	118.4	101.4	43.7	22.	523.	3.13	.89	606.
20.1	.003	118.4	21.1	.003	123.6	106.7	46.0	21.	497.	3.05	.85	590.
21.1	.003	123.6	22.1	.003	128.9	112.0	48.2	21.	473.	2.98	.81	575.
22.1	.003	128.9	23.1	.003	134.1	117.2	50.5	20.	452.	2.91	.77	562.
23.1	.003	134.1	24.1	.002	139.4	122.5	52.8	20.	433.	2.84	.74	549.
24.1	.002	139.4	25.1	.002	144.6	127.7	55.0	19.	415.	2.78	.70	537.
25.1	.002	144.6	26.1	.002	149.8	133.0	57.3	19.	398.	2.72	.68	526.
26.1	.002	149.8	27.1	.002	155.1	138.2	59.6	18.	383.	2.67	.65	516.
27.1	.002	155.1	28.1	.002	160.3	143.5	61.8	18.	369.	2.62	.63	506.
28.1	.002	160.3	30.1	.002	170.7	151.3	65.2	18.	350.	2.57	1.19	497.
30.1	.002	170.7	32.1	.002	181.2	161.8	69.7	17.	328.	2.48	1.11	480.
32.1	.002	181.2	34.1	.002	191.6	172.3	74.2	16.	308.	2.40	1.04	464.
34.1	.002	191.6	36.1	.002	202.0	182.7	78.7	16.	290.	2.33	.98	451.
36.1	.002	202.0	38.1	.002	212.5	193.1	83.2	15.	274.	2.27	.93	438.
38.1	.002	212.5	40.1	.001	222.9	203.6	87.7	15.	260.	2.21	.88	426.
40.1	.001	222.9	42.1	.001	233.3	214.0	92.2	15.	248.	2.15	.84	415.
42.1	.001	233.3	44.1	.001	243.7	224.4	96.7	14.	236.	2.10	.80	405.
44.1	.001	243.7	46.1	.001	254.1	234.8	101.2	14.	226.	2.05	.76	396.
46.1	.001	254.1	48.1	.001	264.5	245.3	105.7	13.	216.	2.00	.73	387.
48.1	.001	264.5	50.1	.001	274.9	255.7	110.2	13.	207.	1.96	.70	379.

C:\FORTRAN\NBSDIST>tkrelief

```
 Please enter remarks
 Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.4
qheat-kW
81

Constnat density heating process

    p       t    rho       M       u d-time
  atm       K   g/cc      kg     j/g   sec.
 5.00    4.50   .137     9.2    8.42
  .27    4.50   .003     9.2   28.03
  .38    6.28   .003     9.2   33.59    .63
  .49    8.05   .003     9.2   39.08    .62
  .61    9.83   .003     9.2   44.63    .63
  .72   11.61   .003     9.2   50.17    .63
  .83   13.39   .003     9.2   55.72    .63
  .95   15.14   .003     9.2   61.17    .62
 1.06   16.92   .003     9.2   66.73    .63
 1.17   18.70   .003     9.2   72.28    .63
 1.29   20.48   .003     9.2   77.83    .63
 1.40   22.23   .003     9.2   83.29    .62

Constant pressure venting process

  t1 rhol     hl    tx rhox     hx heatl     L    Gi  mout  Area dtime  Air
   K g/cc    j/g     K g/cc    j/g   j/g  B/lb         g/s in**2  sec SCFM
22.2 .003  129.5  23.2 .003  134.7 117.9  50.8   20.  687.  3.11   .58  856.
23.2 .003  134.7  24.2 .003  140.0 123.2  53.1   20.  658.  3.04   .56  837.
24.2 .003  140.0  25.2 .003  145.2 128.4  55.3   19.  631.  2.98   .54  819.
25.2 .003  145.2  26.2 .003  150.5 133.7  57.6   19.  606.  2.92   .51  802.
26.2 .003  150.5  27.2 .003  155.7 139.0  59.9   18.  583.  2.86   .49  786.
27.2 .003  155.7  28.2 .002  160.9 144.2  62.1   18.  562.  2.81   .48  772.
28.2 .002  160.9  29.2 .002  166.2 149.5  64.4   18.  542.  2.75   .46  758.
29.2 .002  166.2  30.2 .002  171.4 154.7  66.7   17.  524.  2.71   .44  744.
30.2 .002  171.4  31.2 .002  176.6 159.9  68.9   17.  506.  2.66   .43  732.
31.2 .002  176.6  33.2 .002  187.1 167.8  72.3   17.  483.  2.62   .82  719.
33.2 .002  187.1  35.2 .002  197.5 178.2  76.8   16.  454.  2.54   .77  697.
35.2 .002  197.5  37.2 .002  207.9 188.7  81.3   16.  429.  2.46   .73  677.
37.2 .002  207.9  39.2 .002  218.4 198.8  85.6   15.  408.  2.40   .69  660.
39.2 .002  218.4  41.2 .002  228.8 209.6  90.3   15.  387.  2.33   .65  642.
41.2 .002  228.8  43.2 .002  239.2 220.0  94.8   14.  368.  2.28   .62  626.
43.2 .002  239.2  45.2 .002  249.6 230.4  99.3   14.  352.  2.22   .59  611.
45.2 .002  249.6  47.2 .001  260.0 240.9 103.8   14.  336.  2.17   .57  598.
47.2 .001  260.0  49.2 .001  270.4 251.9 108.5   13.  322.  2.12   .54  583.
49.2 .001  270.4  51.2 .001  280.8 261.7 112.7   13.  310.  2.08   .52  573.
51.2 .001  280.8  53.2 .001  291.3 272.1 117.2   13.  298.  2.04   .50  561.

C:\FORTRAN\NBSDIST>tkrelief
```

```
 Please enter remarks
 Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.6
qheat-kW
108

Constnat density heating process

    p      t    rho        M       u d-time
  atm      K   g/cc       kg     j/g   sec.
 5.00   4.50   .137      9.2    8.42
  .27   4.50   .003      9.2   28.03
  .40   6.59   .003      9.2   34.55    .56
  .53   8.68   .003      9.2   41.05    .55
  .67  10.77   .003      9.2   47.56    .55
  .80  12.86   .003      9.2   54.07    .55
  .93  14.95   .003      9.2   60.58    .55
 1.07  17.02   .003      9.2   67.03    .55
 1.20  19.13   .003      9.2   73.61    .56
 1.33  21.20   .003      9.2   80.06    .55
 1.47  23.31   .003      9.2   86.65    .56
 1.60  25.38   .003      9.2   93.11    .55

Constant pressure venting process

  t1 rho1     h1    tx rhox     hx heatl       L    Gi  mout  Area dtime   Air
   K g/cc    j/g     K g/cc    j/g   j/g    B/lb          g/s in**2   sec  SCFM
25.4 .003 145.9 26.4 .003 151.2 134.5   57.9   19.   803.  3.15   .44 1066.
26.4 .003 151.2 27.4 .003 156.4 139.7   60.2   18.   773.  3.09   .42 1045.
27.4 .003 156.4 28.4 .003 161.6 145.0   62.5   18.   745.  3.03   .41 1026.
28.4 .003 161.6 29.4 .003 166.9 150.3   64.7   18.   719.  2.98   .39 1007.
29.4 .003 166.9 30.4 .003 172.1 155.5   67.0   17.   695.  2.92   .38  990.
30.4 .003 172.1 31.4 .002 177.3 160.7   69.3   17.   672.  2.87   .37  973.
31.4 .002 177.3 32.4 .002 182.6 165.4   71.3   17.   653.  2.84   .35  960.
32.4 .002 182.6 33.4 .002 187.8 171.2   73.8   16.   631.  2.78   .34  942.
33.4 .002 187.8 34.4 .002 193.0 176.4   76.0   16.   612.  2.74   .33  928.
34.4 .002 193.0 36.4 .002 203.5 184.3   79.4   16.   586.  2.70   .64  914.
36.4 .002 203.5 38.4 .002 213.9 194.7   83.9   15.   555.  2.62   .60  888.
38.4 .002 213.9 40.4 .002 224.3 205.2   88.4   15.   526.  2.55   .57  865.
40.4 .002 224.3 42.4 .002 234.7 215.6   92.9   14.   501.  2.49   .54  843.
42.4 .002 234.7 44.4 .002 245.2 226.1   97.4   14.   478.  2.43   .52  823.
44.4 .002 245.2 46.4 .002 255.6 236.5  101.9   14.   457.  2.38   .50  804.
46.4 .002 255.6 48.4 .002 266.0 246.9  106.4   13.   437.  2.32   .48  786.
48.4 .002 266.0 50.4 .002 276.4 257.4  110.9   13.   420.  2.27   .46  770.
50.4 .002 276.4 52.4 .001 286.8 267.8  115.4   13.   403.  2.23   .44  755.
52.4 .001 286.8 54.4 .001 297.2 278.2  119.9   13.   388.  2.19   .42  740.
54.4 .001 297.2 56.4 .001 307.6 288.6  124.3   12.   374.  2.15   .41  726.

C:\FORTRAN\NBSDIST>tkrelief
```

Please enter remarks
Chekk the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.8
qheat-kW
130

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.42	6.90	.003	9.2	35.52	.53
.57	9.30	.003	9.2	43.00	.53
.73	11.71	.003	9.2	50.48	.53
.88	14.11	.003	9.2	57.96	.53
1.03	16.51	.003	9.2	65.45	.53
1.19	18.91	.003	9.2	72.93	.53
1.34	21.34	.003	9.2	80.49	.54
1.49	23.72	.003	9.2	87.93	.53
1.65	26.14	.003	9.2	95.49	.54
1.80	28.52	.003	9.2	102.92	.53

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
28.5	.003	162.3	29.5	.003	167.6	150.6	64.9	18.	863.	3.09	.36	1212.
29.5	.003	167.6	30.5	.003	172.8	156.3	67.3	17.	832.	3.03	.35	1188.
30.5	.003	172.8	31.5	.003	178.1	161.5	69.6	17.	805.	2.98	.34	1168.
31.5	.003	178.1	32.5	.003	183.3	166.8	71.9	17.	780.	2.93	.33	1149.
32.5	.003	183.3	33.5	.003	188.5	172.0	74.1	16.	756.	2.88	.32	1131.
33.5	.003	188.5	34.5	.003	193.7	177.3	76.4	16.	733.	2.84	.31	1114.
34.5	.003	193.7	35.5	.002	199.0	182.5	78.6	16.	712.	2.80	.30	1098.
35.5	.002	199.0	36.5	.002	204.2	187.7	80.9	16.	692.	2.76	.29	1082.
36.5	.002	204.2	37.5	.002	209.4	193.0	83.1	15.	674.	2.72	.28	1067.
37.5	.002	209.4	39.5	.002	219.8	200.8	86.5	15.	647.	2.68	.55	1052.
39.5	.002	219.8	41.5	.002	230.3	211.3	91.0	15.	615.	2.61	.52	1025.
41.5	.002	230.3	43.5	.002	240.7	221.7	95.5	14.	586.	2.55	.50	1000.
43.5	.002	240.7	45.5	.002	251.1	232.1	100.0	14.	560.	2.49	.47	977.
45.5	.002	251.1	47.5	.002	261.6	242.6	104.5	14.	536.	2.43	.45	955.
47.5	.002	261.6	49.5	.002	272.0	253.0	109.0	13.	514.	2.38	.43	935.
49.5	.002	272.0	51.5	.002	282.4	263.4	113.5	13.	493.	2.33	.42	916.
51.5	.002	282.4	53.5	.002	292.8	273.9	118.0	13.	475.	2.29	.40	898.
53.5	.002	292.8	55.5	.002	303.2	284.3	122.5	12.	457.	2.25	.39	881.
55.5	.002	303.2	57.5	.002	313.6	294.7	127.0	12.	441.	2.20	.37	865.
57.5	.002	313.6	59.5	.001	324.0	305.1	131.5	12.	426.	2.17	.36	850.

C:\FORTRAN\NBSDIST>tkrelief

```
 Please enter remarks
 Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
2
qheat-kW
157

Constnat density heating process

    p      t    rho        M        u d-time
  atm      K   g/cc       kg      j/g   sec.
 5.00   4.50   .137      9.2     8.42
  .27   4.50   .003      9.2    28.03
  .44   7.22   .003      9.2    36.51    .50
  .61   9.94   .003      9.2    44.97    .50
  .79  12.66   .003      9.2    53.43    .50
  .96  15.38   .003      9.2    61.90    .50
 1.13  18.09   .003      9.2    70.38    .50
 1.31  20.81   .003      9.2    78.86    .50
 1.48  23.53   .003      9.2    87.34    .50
 1.65  26.25   .003      9.2    95.83    .50
 1.83  28.97   .003      9.2   104.31    .50
 2.00  31.69   .003      9.2   112.79    .50

Constant pressure venting process

  t1 rhol    h1    tx rhox    hx heatl      L    Gi  mout  Area dtime  Air
   K g/cc   j/g     K g/cc   j/g   j/g   B/lb          g/s in**2   sec SCFM
31.7 .003 178.9 32.7 .003 184.1 167.7   72.2   17.   936.  3.15   .30 1384.
32.7 .003 184.1 33.7 .003 189.3 172.9   74.5   16.   908.  3.10   .29 1362.
33.7 .003 189.3 34.7 .003 194.6 178.2   76.8   16.   881.  3.05   .28 1342.
34.7 .003 194.6 35.7 .003 199.8 183.4   79.0   16.   856.  3.01   .28 1322.
35.7 .003 199.8 36.7 .003 205.0 188.7   81.3   15.   832.  2.96   .27 1303.
36.7 .003 205.0 37.7 .003 210.3 193.9   83.5   15.   810.  2.92   .26 1285.
37.7 .003 210.3 38.7 .003 215.5 199.1   85.8   15.   788.  2.88   .25 1268.
38.7 .003 215.5 39.7 .002 220.7 204.4   88.1   15.   768.  2.85   .25 1251.
39.7 .002 220.7 40.7 .002 225.9 209.6   90.3   15.   749.  2.81   .24 1235.
40.7 .002 225.9 42.7 .002 236.3 217.4   93.7   14.   722.  2.77   .46 1220.
42.7 .002 236.3 44.7 .002 246.8 227.9   98.2   14.   689.  2.71   .44 1191.
44.7 .002 246.8 46.7 .002 257.2 238.3  102.7   14.   659.  2.65   .42 1164.
46.7 .002 257.2 48.7 .002 267.6 248.8  107.2   13.   631.  2.59   .41 1138.
48.7 .002 267.6 50.7 .002 278.0 259.2  111.7   13.   606.  2.54   .39 1115.
50.7 .002 278.0 52.7 .002 288.5 269.6  116.2   13.   582.  2.49   .37 1093.
52.7 .002 288.5 54.7 .002 298.9 280.0  120.7   12.   561.  2.44   .36 1072.
54.7 .002 298.9 56.7 .002 309.3 290.5  125.1   12.   541.  2.39   .35 1052.
56.7 .002 309.3 58.7 .002 319.7 300.9  129.6   12.   522.  2.35   .34 1033.
58.7 .002 319.7 60.7 .002 330.1 311.3  134.1   12.   504.  2.31   .32 1016.
60.7 .002 330.1 62.7 .002 340.5 321.7  138.6   12.   488.  2.27   .31  999.

C:\FORTRAN\NBSDIST>tkrelief
```

```
 Please enter remarks
 Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
2.5
qheat-kW
216

Constnat density heating process

    p      t    rho       M       u d-time
  atm      K   g/cc      kg     j/g   sec.
 5.00   4.50   .137     9.2    8.42
  .27   4.50   .003     9.2   28.03
  .49   8.00   .003     9.2   38.94    .47
  .71  11.50   .003     9.2   49.83    .46
  .94  15.00   .003     9.2   60.73    .46
 1.16  18.49   .003     9.2   71.60    .46
 1.38  21.99   .003     9.2   82.52    .47
 1.61  25.49   .003     9.2   93.44    .47
 1.83  28.99   .003     9.2  104.37    .47
 2.05  32.49   .003     9.2  115.28    .47
 2.28  35.99   .003     9.2  126.20    .47
 2.50  39.49   .003     9.2  137.13    .47

Constant pressure venting process

  t1  rho1     h1    tx  rhox     hx  heatl       L    Gi  mout   Area dtime   Air
   K  g/cc    j/g     K  g/cc    j/g    j/g    B/lb         g/s  in**2   sec  SCFM
39.5 .003 219.6 40.5 .003 224.9 208.8   89.9   15.  1035.  3.10   .22 1702.
40.5 .003 224.9 41.5 .003 230.1 214.0   92.2   14.  1009.  3.06   .21 1681.
41.5 .003 230.1 42.5 .003 235.3 219.2   94.5   14.   985.  3.02   .21 1660.
42.5 .003 235.3 43.5 .003 240.5 224.5   96.7   14.   962.  2.99   .20 1640.
43.5 .003 240.5 44.5 .003 245.7 229.7   99.0   14.   940.  2.95   .20 1621.
44.5 .003 245.7 45.5 .003 251.0 234.9  101.2   14.   919.  2.92   .20 1603.
45.5 .003 251.0 46.5 .003 256.2 240.2  103.5   14.   899.  2.89   .19 1585.
46.5 .003 256.2 47.5 .003 261.4 245.4  105.7   13.   880.  2.85   .19 1568.
47.5 .003 261.4 48.5 .003 266.6 250.6  108.0   13.   862.  2.82   .18 1552.
48.5 .003 266.6 50.5 .002 277.0 258.4  111.3   13.   836.  2.79   .36 1535.
50.5 .002 277.0 52.5 .002 287.5 268.9  115.8   13.   803.  2.74   .34 1505.
52.5 .002 287.5 54.5 .002 297.9 279.3  120.3   13.   773.  2.69   .33 1476.
54.5 .002 297.9 56.5 .002 308.3 289.7  124.8   12.   746.  2.64   .32 1448.
56.5 .002 308.3 58.5 .002 318.7 300.2  129.3   12.   720.  2.59   .31 1423.
58.5 .002 318.7 60.5 .002 329.1 310.6  133.8   12.   695.  2.54   .30 1398.
60.5 .002 329.1 62.5 .002 339.5 321.0  138.3   12.   673.  2.50   .29 1375.
62.5 .002 339.5 64.5 .002 350.0 331.4  142.8   11.   652.  2.46   .28 1353.
64.5 .002 350.0 66.5 .002 360.4 341.8  147.3   11.   632.  2.42   .27 1332.
66.5 .002 360.4 68.5 .002 370.8 352.2  151.8   11.   613.  2.39   .26 1312.
68.5 .002 370.8 70.5 .002 381.2 362.7  156.3   11.   596.  2.35   .25 1293.

C:\FORTRAN\NBSDIST>type tkrelief.lst
```

```
Calculation of pressure drop for
helium flowing in a round pipe
Enter mass flow rate in gm/s
523
Enter pressure in atm
1.2
Enter inlet temperature in degree k
19.1
Enter outlet temperature in degree k
19.1
Enter length of pipe in meter
10
Enter pipe diameter in cm
14

                    PROGRAM DPROUND
          INPUT DATA
      FIN          PIN          TIN         TOUT       LENGTH          D
      G/S          ATM            K            K            M         CM
    523.00         1.20        19.10        19.10        10.00      14.00

Do you satisfy this input data (y/n) ?
y

               CALCULATED DATA
   FLOW AREA(SQ CM)    153.938
   ABSOLUTE ROUGHNESS(CM)   .152E-03
   RELATIVE ROUGHNESS   .109E-04


seg.      p      t       rho         v        visc        rey       fric      segdp vel head
        atm      k      g/cc      cm/s     g/cm-s                             atm       atm
   1   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.50E-04  1.86E-03
   2   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.50E-04  1.86E-03
   3   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.50E-04  1.86E-03
   4   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03
   5   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03
   6   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03
   7   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03
   8   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03
   9   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03
  10   1.20  19.10  3.07E-03  1.11E+03  3.49E-05  1.36E+06  1.14E-02  1.51E-04  1.86E-03


                    TOTAL PRESSURE DROP IS       .002 ATM

Do you want another pressure drop calculation (y/n) ?
y
```